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The Connection Between Local Sea Level Rise, Climate Change and Ocean Circulation

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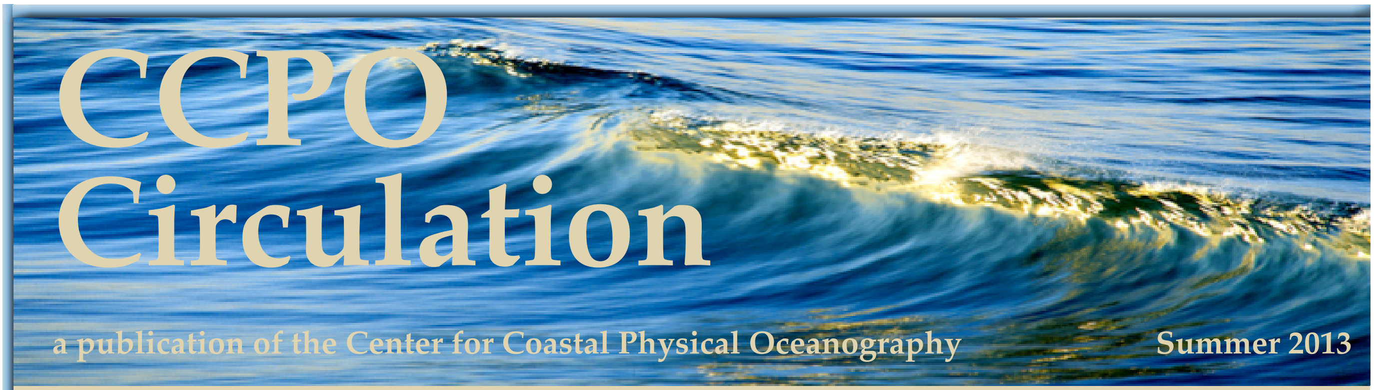

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The connection between local sea level rise, climate change and ocean circulation

By Tal Ezer and Larry P. Atkinson

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In this Issue:

In recent years, Norfolk has become a symbol for a city that is already battling the impact of sea level rise (SLR). Street flooding during high tides (Fig. 1, left) is much more common now than in the past, and storm surges (Fig. 1, right) are more severe and last longer. Therefore, as part of Old Dominion University's Climate Change and Sea Level Rise Initiative (CCSLRI), CCPO scientists focus on studies that enhance our understanding of the causes of local SLR and improve our ability to predict future SLR. This information can help policy makers, insurers, city planners and other stakeholders who are addressing the consequences of SLR for an urban area. (Atkinson et al., 2013). (*continued on pg. 2*)

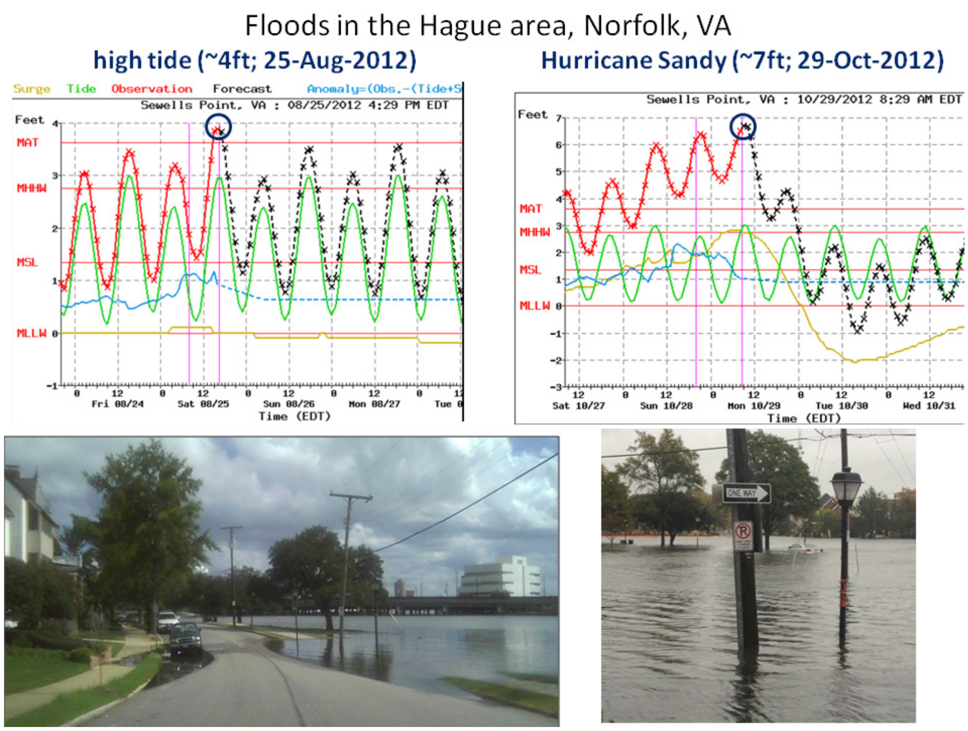

Fig. 1*. Water level from NOAA prediction (top) and pictures of floods in the Hague area of Norfolk during the same time (bottom). Left panels represent minor flooding during a high tide and right panels are during hurricane Sandy. Green, red, orange and blue lines are the tidal prediction, observations, storm surge and anomaly (forecast error). Note that in both periods, observed water level was about 1 foot above the NOAA storm and tide prediction; this anomaly may have been associated with a change in Atlantic Ocean currents, as suggested by Ezer et al., 2013.*

THE CONNECTION BETWEEN LOCAL SEA LEVEL RISE, CLIMATE CHANGE AND OCEAN CIRCULATION *(cont'd. from pg.1)*

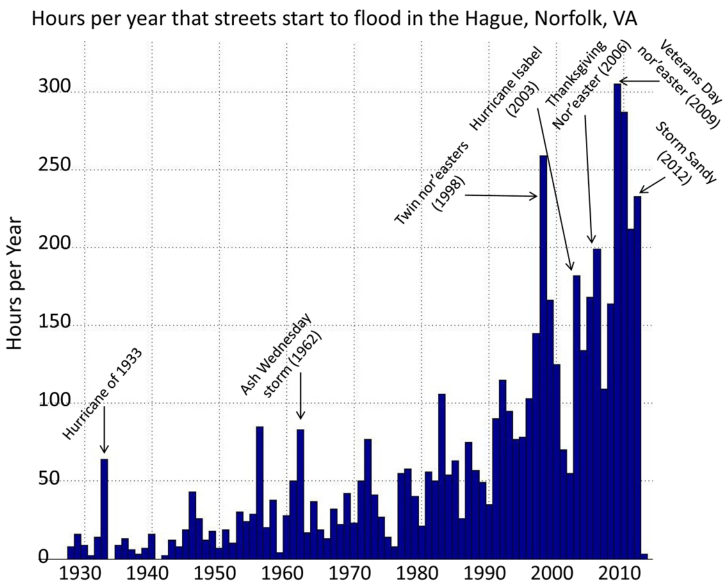

Fig. 2. *The number of hours per year that streets in the Hague area start to flood (~4ft or 1.2m above MLLW). Some of the major storms that passed through the region are indicated.*

Statistics of the frequency of flooding (Fig. 2) show that before the 1980s, streets in the Hague area of Norfolk flooded on average only ~20 hours/year, and severe floods occurred mostly during major storms or hurricanes. However, over the past decade or so, flooding increased dramatically to ~150-300 hours/year, and storm surges that occurred in the past every 30 years, now occur every five years.

So why has the risk of floods in the Hampton Roads area increased so dramatically? The reason is that local sea level is rising in this region much faster (~4-6 mm/year) than global SLR (~1.5 mm/year) from global tide gauges since the early 1900s and ~3.2 mm/year from altimeter data since 1993. Moreover, recent studies show that SLR in this region is accelerating (Sallenger et al., 2012; Boon, 2012; Ezer and Corlett, 2012a), so the region between Cape Hatteras and Cape Cod is now called an "accelerated SLR hotspot."

To understand the causes of relative coastal SLR (observed local SLR relative to land), one must consider three main components: 1) global SLR due to melting ice sheets and thermal expansion of sea water, 2) land movement (e.g., land in the Chesapeake Bay area is sinking due to post-glacial rebound) and 3) changes in ocean dynamics. The last component includes climatic changes in ocean circulation that are not yet well understood.

Climate models predict that in the future, a warmer climate will slow the Atlantic Meridional Overturning Circulation (AMOC) and the Gulf Stream (GS). As a result of the GS, the sea level along the mid-Atlantic coast on the onshore side of the GS is maintained at ~1m lower than the sea level in the offshore side of the GS (Fig. 3). Since the GS surface current is proportional to the sea level gradient across the stream, changes in the GS could potentially affect the coastal sea level along the U.S. East coast (Fig. 3). This theoretical framework is based on physical oceanographic principles and climate model predictions. However, the main question is whether or not observations can confirm this theory, and that is the purpose of the recent study by Ezer et al., (2013). (*continued on pg. 4*)

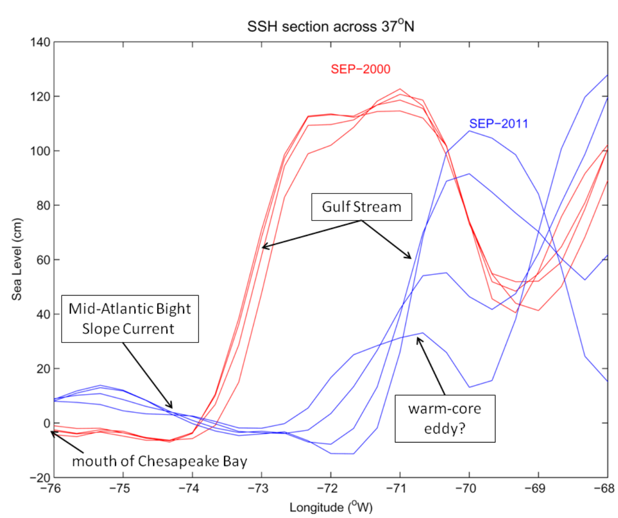

Fig. 3. *Examples of sea surface heights from satellite altimeter data at weekly intervals from September 2000 (red) and September 2011 (blue). The cross section is along 37°N, from the mouth of the Chesapeake Bay in the west to the GS in the east. Note that when the GS moved offshore and was less robust in 2011, sea level in the Chesapeake Bay rose by ~12cm relative to 2000.*

Ezer et al., (2010) analyzed the GS elevation gradient obtained from satellite altimeter data, the Florida Current transport obtained from cable measurements across the Florida Straits, and coastal sea level obtained from 10 tide gauge stations in the Chesapeake Bay and the mid-Atlantic coast. They used an Empirical Mode Decomposition (EMD) method to separate oscillating modes from decadal and long-term trends (Fig. 4); the method was introduced for the first time for studies of SLR trends by Ezer and Corlett (2012a,b).

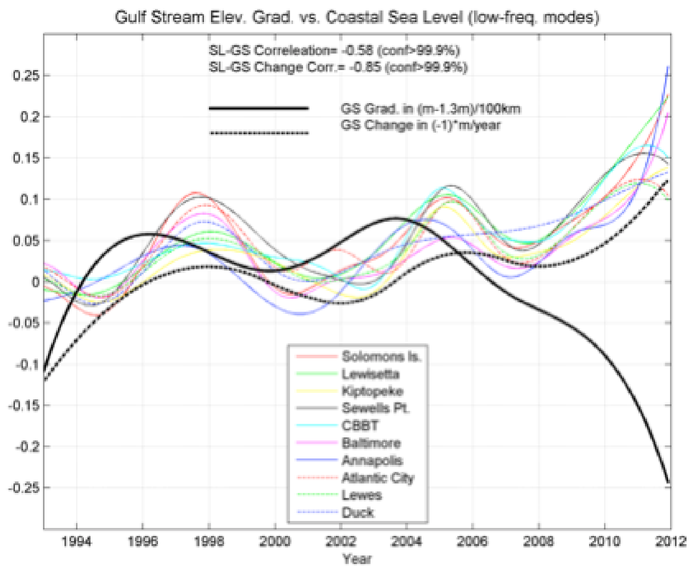

Fig. 4. *Observed sea level variations obtained for the low-frequency modes of the EMD analysis of tide gauge stations (colored lines). The black solid line is the elevation gradient across the Gulf Stream (in m relative to 1.3m over 100km) and black dash line is the reverse change of the gradient with time (e.g., the GS gradient increased by ~0.12 m/y in 1993 but decreased by ~0.12 m/y in 2012; this is equivalent to ~10% change in GS strength per year).*

Somewhat surprising was the high coherency found between sea level records located hundreds of kilometers apart in different coastal environments (colored lines in Fig. 4). Why, for example, would sea level in Atlantic City, NJ, have the same oscillations as those well inside the Chesapeake Bay at Baltimore, M.D., or along the Outer Banks coast at Duck, N.C., if not for a common forcing from the GS?. In fact, changes in the GS strength were found to be highly correlated with variations in SL on time scales ranging from months to decades and longer. It also appears that the GS started weakening around 2004, which was followed by an increase in coastal sea level at all the stations after 2007. While climate-related weakening of the AMOC and the GS has been predicted by climate models, the new findings show that this critical aspect of climate change may have started already, and probably explain the "accelerated SLR hotspot" phenomenon (land subsidence is a slow process that cannot contribute to fast changes in SLR).

More studies are needed to better understand the impact of climate-related changes in ocean dynamics on SLR and use of this information to improve regional projections of SLR. The study may also open the door for improved short-term flood risk predictions by monitoring real-time variations in the GS.

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